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Operating Cost Comparison
Fluidized Bed Boilers
vs
Conventional Stoker Fired Coal
Or Oil Fired Boilers

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1.0 Introduction

In November 1982 the Government of Canada Department of Energy Mines and Resources engaged Lavalin Inc. to compare operating costs of the fluidized bed boiler plant recently installed at CFB Summerside P.E.I. to an equivalent plant utilizing stoker fired boilers burning low sulphur coal. Later the study was expanded to include comparative operating cost of an equivalent oil fired plant.

2.0 Scope

The operating cost comparison is based on a 20-year life cycle for the plant and considers the following costs:

- Fuel cost
- Limestone sorbent cost
- Fuel handling cost
- Waste disposal cost
- Electric power cost
- Staffing requirements
- Equipment maintenance cost
- Miscellaneous costs

Costs for each type of boiler installation are calculated for the year 1983. We compare the cost to operate each type of plant over its expected 20 year useful life by multiplying 1983 costs by appropriate present worth multipliers.

3.0 Summary and Conclusions

Present costs to operate the three types of steam plant studied are:

<u>TYPE OF BOILERS</u>	<u>1983 OPERATING COST</u>
Fluidized bed coal	\$ 2,425,000
Stoker fired coal	\$ 1,990,000
Bunker C oil	\$ 2,200,000.

To compare the cost to operate the different types of plants over 20 years, we apply present worth multipliers to 1983 costs. The multipliers, obtained from a 1982 Energy Mines and Resources publication, (see reference 4, in the List of References in the Appendix) reflect different escalation rates for fuel oil, electricity and other costs. The calculation "Present Worth of 20 Year Operating Cost" is detailed in Table 5 of the Appendix and summarized below:

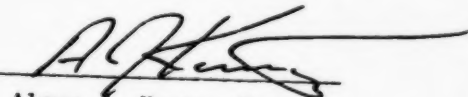
<u>TYPE OF BOILERS</u>	<u>PRESENT WORTH OF 20-YEAR OPERATING COST</u>
Fluidized bed coal	\$ 25 million
Stoker fired coal	\$ 21 million
Bunker C oil	\$ 27 million

The advantage that fluidized bed coal boilers have over conventional coal fired boilers is their ability to utilize, in an environmentally acceptable manner, high sulphur coal without the problems encountered with the use of flue gas scrubbers. It seems reasonable that coal with high sulphur content should be cheaper than low sulphur coal; after all the user is spared the expense of sulphur removal. In today's market however that is not the case. Sulphur content seems to have little effect on the price of coal.

3.0 Summary and Conclusions (Cont'd)

In the future, depending on air pollution laws, cost to scrub flue gas, demand and availability of coal, it is possible that the price of high sulphur coal could be considerably less than that of low sulphur imported coal. In that case the economics of operating the fluidized bed boilers would be more favorable.

Prepared by:


Aloys J. Kuntz, Eng.

4.0 Discussion of Operating Costs

4.1 Fuel Quantities and Cost

Fuel quantity is based on records of fuel consumption for the year 1977 (1). A total of 12,234 short tons of coal with a heating value of 12,900 BTU/lb were consumed. Assuming 70% boiler efficiency total steam production would be:

$$\frac{12,324 \text{ ton} \times 2,000 \text{ lb/ton} \times 12,900 \text{ BTU/lb}}{1,000 \text{ BTU/lb steam}} \times 0.70 = 221 \text{ million lb}$$

Fuel quantities for the different types of plants considered are based on this steam production taking into consideration the heat value and operating efficiency for each particular case.

Foster Wheeler Limited guarantee 80% efficiency for their fluidized bed boiler when operated at loads above 50% MCR. This efficiency includes the heat formation to convert limestone to calcium sulphate.

A new stoker fired boiler with air heater or economizer could also be expected to operate at 80% efficiency.

It is possible to operate oil fired boilers at a lower excess air level than stoker fed coal boilers and with negligible carbon loss, thus we apply an efficiency of 82% to oil fired boilers.

A fluidized bed boiler will be difficult to control below 25% capacity and electric power consumption is high (25 kW.hr per 1000 lb steam vs 8 kW.hr at full load and 12 kW.hr at 60% capacity). During the four summer months, June, July, August and September, according to 1977 plant records, coal consumption was 1870 tons for a steam production of:

$$\frac{1,870 \text{ tons} \times 2,000 \text{ lb/ton} \times 12,900 \text{ BTU/lb}}{1000 \text{ BTU/lb}} \times 0.70 = 34 \text{ million lb.}$$

4.0 Discussion of Operating Costs (Cont'd)

4.1 Fuel Quantities and Cost (Cont'd)

Average steam production was:

$$\frac{34,000,000 \text{ lb}}{122 \text{ days} \times 24 \text{ hr/day}} = 11,600 \text{ lb/hr}$$

which is less than 30% capacity of one fluidized bed boiler. During the 4 summer months the plant should use the two 10,000 lb/hr stoker fired boilers in No. 2 heating plant.

By the same token it would be difficult to operate a new larger stoker fired unit during the summer and maintain high efficiency. We assume therefore that, had new larger stoker fired boilers been installed, summer operation would be at 70% efficiency.

When operating stoker fired boilers without equipment to remove sulphur from the flue gas it will be necessary to burn coal with 1% sulphur content in order to meet the SO_2 emission guideline of 1.64 lb/million BTU heat input (2). The best local coal is Springhill coal with 1.9% sulphur. It will be necessary therefore to import low sulphur coal from Pennsylvania or Kentucky for operation of new stoker fired boilers and for summer operation of the existing stoker boilers.

Typical analysis and prices of the coals in consideration are shown in Table 1.

4.0 Discussion of Operating Costs (Cont'd)4.1 Fuel Quantities and Cost (Cont'd)

TABLE 1
COAL ANALYSIS AND PRICE

<u>Name and/or location of mine</u>	<u>Typical Analysis - As Rec'd</u>			<u>1982 Price</u>	
	<u>Sulphur % by wt.</u>	<u>Ash % by wt.</u>	<u>Heat BTU/lb</u>	<u>\$/Tonne</u>	<u>\$/10⁶ BTU</u>
Evans Cape Breton	6	15 - 20	11,000	80.	3.30
Prince Cape Breton (Unwashed)	4.5	18	11,000	80.	3.30
Prince Cape Breton (Washed coal)	2.6	8.3	13,100	100	3.47
Springhill	1.9	16	11,200	75	3.04
Pennsylvania (by barge)	0.8	7.5	13,500	105	3.54
Pennsylvania (small quantity by rail)	0.8	7.5	13,500	125	4.21

- Notes: 1. Prices for Canadian coals are based on recent quoted prices with allowances for transportation unloading and piling in Summerside.
2. Prices for low sulphur US coal are budget prices, in Canadian dollars, provided by a coal supplier, unloaded & piled in Summerside.
3. Tonne is metric tonne (2200 lb)
4. Prices are rounded to nearest \$5.

4.0 Discussion of Operating Costs (Cont'd)

4.1 Fuel Quantities and Cost (Cont'd)

Coal consumption in a fluidized bed boiler plant with summer operation of the small stoker boilers is calculated as follows:

- For fluidized bed boilers:

$$\frac{187,000,000 \text{ lb steam/yr} \times 1,000 \text{ BTU/lb steam}}{2,200 \text{ lb/tonne} \times 11,000 \text{ BTU/lb} \times 0.80} = 9,660 \text{ tonnes/year}$$

$$\frac{34,000,000 \text{ lb steam/yr} \times 1,000 \text{ BTU/lb steam}}{2,200 \text{ lb/tonne} \times 13,500 \text{ BTU/lb} \times 0.70} = 1,600 \text{ tonnes/year}$$

- Coal consumption for a new stoker fired steam plant is calculated to be:

$$\frac{187,000,000 \text{ lb steam/yr} \times 1,000 \text{ BTU/lb steam}}{2,200 \text{ lb/tonne} \times 13,500 \text{ BTU/lb} \times 0.80} = 7,870$$

$$\frac{34,000,000 \text{ lb steam/yr} \times 1,000 \text{ BTU/lb steam}}{2,200 \text{ lb/tonne} \times 13,500 \text{ BTU/lb} \times 0.70} = 1,600$$

9,470 tonnes/year

- No. 6 or Bunker C fuel with nominal sulphur content of 3% is estimated to cost \$35. per barrel at Summerside. The premium for low sulphur (1.5%) Bunker C oil in Montreal is \$3.50 per barrel. We assume the same differential would apply to low sulphur oil delivered to P.E.I. so price for that fuel is \$38.50 per barrel. The quantity of oil is calculated to be:

$$\frac{221,000,000 \text{ lb steam/yr} \times 1,000 \text{ BTU/lb steam}}{35 \text{ gal/bbl} \times 180,000 \text{ BTU/gal} \times 0.82} = 42,800 \text{ bbl}$$

4.2 Limestone Quantity and Cost

Limestone reacts with sulphur dioxide in the furnace to form calcium sulphate in the following reaction:



to stay within allowable SO₂ emission when burning 6% sulphur coal 0.055 lb sulphur/lb coal or 0.11 lb SO₂/lb coal.

4.0 Discussion of Operating Costs (Cont'd)

4.2 Limestone Quantity and Cost (Cont'd)

must be reacted. Theoretical limestone required is:

$$\frac{200}{128} \times 0.11 = 0.172 \text{ tonne/tonne of coal}$$

In order to meet environmental guidelines a Ca/S ratio of 2 to 3 is required. for purpose of calculation we use $0.172 \times 2.9 = 0.50$ tonne per tonne of coal.

When burning 9,600 tonne of high sulphur coal actual limestone required is: $9,600 \frac{\text{tonne/yr}}{\text{tonne}} \times 0.50 \text{ tonne} = 4,830 \text{ tonne}$

Double screened limestone f.o.b. Summerside is \$35/tonne while screenings (under 1/4 inch) cost \$16/tonne. Initial operation indicates that double screened limestone must be used so cost is based on \$35/tonne.

It should be noted that if Springhill coal is burned, limestone quantity would be reduced to about 1500 tonne per year but coal cost should not increase.

4.3 Coal Handling and Ash Disposal

Transportation of coal and ash from storage piles on the base to the boilerhouse is handled by an independent contractor. We use a price of \$1.90/tonne for coal handling, \$1.00/tonne for normal ash disposal and \$5.00/tonne for disposal of the mixture of ashes, calcium sulphate and unreacted limestone.

The unit prices for coal and ash handling are based on actual prices paid in past years (the base actually pays somewhat less this season but the same price may not be available in future years). The cost to dispose of calcium sulphate and ash includes the cost to bury the mixture and is based on a price of \$5.75/m³ (or about \$3.00/tonne) obtained by the base this year.

4.0 Discussion of Operating Costs (Cont'd)

4.3 Coal Handling and Ash Disposal (Cont'd)

Although a small part of overall operating costs, it is possible to reduce disposal costs by using low sulphur coal.

Ash quantity per tonne of coal is given in the fuel analysis. Calcium sulphate plus unreacted limestone is calculated to be 0.65 tonne/tonne of 6% sulphur coal.

4.4 Electrical Power

Electrical power requirements for a fluidized bed boiler are high relative to conventional burning techniques. The high power consumption is attributed mostly to fan power required to maintain the bed in suspension. In addition, there is a relatively large ash re-injection system, a separate limestone handling system and increased ash handling. Furthermore, electrical power input remains relatively constant as steam load is reduced causing specific power consumption (kW.hr/1000 lb of steam) to increase dramatically at low load.

The fluidized bed boiler installation at Washington D.C. is similar to the Summerside installation. From tests carried out in Washington (3) specific power consumption in kW.hr/1000 lb of steam varies from 8 at maximum continuous rating (MCR) to 12 at 60% MCR and 25 at 25% MCR.

We studied a number of modern oil and wood fuel fired installations, extrapolating for stoker fired coal requirements to come up with the following specific power requirements for equivalent oil and coal fired plants:

Oil fired 1.5 kW.hr/1000 lb steam

Stoker coal fired 3.3 kW.hr/1000 lb steam

4.0 Discussion of Operating Costs (Cont'd)

4.4 Electrical Power (Cont'd)

In each case power requirements are based on an average boiler steaming rate of 60% MCR.

As discussed in Article 4.1, during summer months steam load will be too small for practical operation of a fluidized bed boiler. Table 2 demonstrates the relative cost of fuel and electric power at a steam rate of 10,000 lb/hr (25% MCR):

TABLE 2
COMPARATIVE FUEL & ELECTRIC POWER COSTS

	<u>COST \$/HR @ 10,000 LB STEAM/HR</u>		
	<u>FUEL</u>	<u>ELECTRICITY</u>	<u>TOTAL</u>
Fluidized bed boiler	47.10	23.75	70.85
Stoker fired boiler	50.60	3.80	<u>54.40</u>
Difference			16.45

By operating the small stoker fired boilers in the summer electric power costs should be reduced by \$16 per hour or about \$12,000 per month.

Electrical power rate was obtained from the base purchasing authority. There is no demand charge and the power rate varies slightly month to month depending on the power commission's actual fuel cost. Currently power is 9.5¢/kW.hr and that rate is used for our calculations.

4.0 Discussion of Operating Costs (Cont'd)

4.5 Manning Requirements

The number of operators and maintenance personnel is shown on Table 3 in the Appendix.

In each case there would be two people per shift to operate the boilers and one fuel handler per shift for the coal fired plants. Maintenance mechanics, who also replace during the swing shift and vacation period are allocated in proportion to the relative complexity of the plant. For the oil fired plant these men would also be responsible for oil unloading.

The existing stoker fired boilers have only a few simple controls that require little maintenance. The new fluidized bed boilers (and any new boiler installation for that matter) have large and complex analogue and logic control systems that will require instrument/electrical technicians to maintain. Since it is not likely that this sort of help is readily available in Summerside from an outside firm, we have provided for two technicians for each type of plant.

4.6 Major Maintenance

Every plant requires replacement of components from time to time. Although we could not find figures for a boiler plant only, in the pulp and paper industry (as an example), maintenance costs vary from 2% to 10% per year of installed capital costs. We used 4% of capital costs which is in addition to the maintenance workers already provided for in article 4.5 above which makes total maintenance somewhat more than 5%.

Capital cost for the fluidized bed boiler plant is \$14 million, for an equivalent stoker fired boiler plant \$12.2 million (11.7 million per approval of capital project memo, Treasury Board of Canada, File 80-122, 19/2/81, plus 0.5 million for electrostatic precipitators) and \$5 million for an equivalent oil fired plant (extrapolated from costs for recent plants).

4.0 Discussion of Operating Costs (Cont'd)

4.7 Miscellaneous costs

a) Steam for ash handling and soot blowing

Plant steam production is based on the existing operation which includes steam for soot blowing and to produce vacuum for ash handling. Steam required for these services will not differ appreciably when operating fluidized bed boilers or new stoker fired units. Oil fired boilers do not require ash handling however see item 'b' following.

b) Oil heating and atomizing

We estimate that, in the case of oil fired boilers, fuel oil heating and atomizing steam will be equal to the steam required for ash handling with coal burning facilities.

c) Interest cost on fuel

Coal for a full year's operation is purchased and, we presume, paid for in the summer. If oil is fired it would be received by railway tank car year around with only 1 to 2 months fuel inventory. No allowance is made for extra inventory cost for coal fuel.

d) Capital cost

The operating costs do not include interest charges on the capital costs of the plants.

e) Extra start-up and testing costs

Since fluidized bed burning is relatively new technology there will undoubtedly be larger than usual start-up costs associated with this installation. In addition it is likely that various types of coal, some wood and perhaps other fuels will be tested in this facility.

No allowance is made in the operating estimates for these costs.

5.0 Present Worth of 20 Year Operating Costs

Table 4 in the Appendix details the calculation of the present worth of operating costs over the next 20 years.

Stated in another way, the present worth of the 20 year life cycle operating costs represents the amount of money that would have to be invested now to finance plant operation over the 20 year period 1983 to 2003.

APPENDIX

TABLE 3

OPERATING COSTS FOR YEAR 1983

ITEM	FLUIDIZED BED BOILERS WITH NO. 2 CENTRAL MTG. PLANT		CONVENTIONAL STOKER COAL BOILERS WITH LOW S ₂ FUEL		OIL FIRED BOILERS WITH LOW S ₂ FUEL OIL	
	QUANTITY AND UNIT PRICE	COST (\$)	QUANTITY AND UNIT PRICE	COST (\$)	QUANTITY AND UNIT PRICE	COST (\$)
1. Fuel:						
- Cape Breton coal 6% sulphur 11,000 BTU/lb	9,600 tonne @ \$80/tonne	\$773,000	N/A		N/A	
- Pennsylvania coal 0.8% sulphur 13,500 BTU/lb	1,600 tonne @ \$125/tonne	\$200,000	9,470 tonne @ \$105/tonne	\$ 994,000	N/A	
- Bunker C oil 1 1/2% sulphur 180,000 BTU/l gal	N/A		N/A		42,800 bbl @ \$38.50/bbl	\$1,648,000
2. Limestone	4,830 tonne @ \$35/tonne	\$169,000	N/A		N/A	
3. Coal handling	11,260 tonne @ \$1.90/tonne	\$ 21,000	9,470 tonne @ \$1.90/tonne	\$ 18,000	N/A	
4. Ash handling and disposal	6,400 tonne @ \$3./tonne	\$ 19,000	750 tonne @ \$1.00/tonne	\$ 1,000	N/A	
5. Electric power	12 kW. hr/1000 X 187 million 3.0 kW. hr/1000 X 34 million @ 9.5¢/kW.hr	\$223,000	3.3 kW.hr/1000 X 221 million @ 9.5¢/kW.hr	\$ 70,000	1.5 kW.hr/1000 X 221 million @ 9.5¢/kW.hr	\$ 32,000
6. Operators:						
- Chief operator	1 HP5 25,400		1 HP5 25,400		1 HP5 25,400	
- Shift supervisors	4 HP4 93,600		4 HP4 93,600		4 HP4 93,600	
- Boiler operators	4 HP3 82,400		4 HP3 82,400		4 HP3 82,400	
- Fuel handlers	4 HP2 78,800		4 HP2 78,800		-	
		\$280,000		\$ 280,000		\$ -201,000
7. Maintenance						
- Mechanics and shift replacement	6 120,000		4 80,000		3 60,000	
- Instrument/Elect. Technicians	2 60,000		2 60,000		2 60,000	
		\$180,000		\$ 140,000		\$ 120,000
8. Allowance for major maintenance	4% of 14 million	\$560,000	4% of 12.2 million	\$ 488,000	4% of 5 million	\$ 200,000
TOTAL:		\$ 2,425,000		\$1,991,000		\$ 2,201,000
COST BREAKDOWN (Carried to Table 4)						
OIL						
ELECTRICITY		\$223,000		\$ 70,000		\$ 1,648,000
OTHER COSTS		\$ 2,202,000		\$1,921,000		\$ 521,000

TABLE 4

PRESENT NORTH OF 20 YEAR LIFE CYCLE OPERATING COSTS

<u>COMMODITY</u>	<u>20 YEAR PRESENT NORTH MULTIPLIER (4)</u>	<u>FLUIDIZED BED BOILERS WITH NO. 2 CENTRAL HEATING PLANT 1983*</u> 20 YEAR	<u>CONVENTIONAL STOKER COAL BOILERS WITH LOW SULPHUR FUEL 1983*</u> 20 YEAR	<u>OIL FIRED BOILERS WITH LOW SULPHUR FUEL OIL 1983*</u> 20 YEAR
OIL	12.566	-	-	\$1,648,000 \$20,709,000
ELECTRICITY	8.664	\$ 223,000 \$ 1,932,000	\$ 70,000 \$ 606,000	\$ 32,000 \$ 277,000
OTHER	10.594	\$2,202,000 \$23,328,000	\$1,921,000 \$20,351,000	\$ 521,000 \$ 5,519,000
TOTAL		\$25,260,000	\$20,957,000	\$26,505,000
ROUNDED		\$25 MILLION	\$21 MILLION	\$27 MILLION

*From Table 3 "Operating Costs for Year 1983".

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